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A MODULAR PLATFORM FOR FUSION OF IMAGES

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ABSTRACT

This paper presents a platform for the assessment of strategies for the fusion of images of various modalities and having different spatial resolution. The purpose of the fusion is the synthesis of multimodal images offering the best spatial resolution available in the data set. These synthesized images should be as close as possible to reality. This platform is written in IDL. It calls upon the ARSIS concept and thus comprises three categories of models. For each category, several models were implemented. Each model of a given category may be combined with models of the other categories, thus offering several possible strategies. The part « quality assessment » provides quantitative values for the fusion. It can also be executed, independently from the fusion part, on images resulting from a fusion process outside the platform. The platform should be made public.

1. INTRODUCTION

Several imaging systems of Earth observation deliver multispectral (MS) and panchromatic (Pan) images having different spatial resolutions. Many studies demonstrated the interest of having multispectral images offering the highest spatial resolution available in the data set for a better modeling of the environment. The interest in creating images representing what would be observed by a multispectral sensor at a higher spatial resolution is real in spatial domain. A performing synthesis method would allow to work with simpler and less expensive sensors. Hence, an economy of space and weight on board.

This can be performed by fusion techniques, which propose a unique exploitation of the data originally coming from individual sources. The fusion method must take into account the physical properties of each modality when increasing the resolution of the multispectral image.

The most famous fusion techniques are Intensity-Hue-Saturation (IHS) [2] and Principal Component Analysis (PCA) [10]; they are integrated in most fusion software.

Their main drawback is that they are limited to cases where the high resolution image and the low resolution one are highly correlated [14]. Several methods have been recently developed based on multi-resolution analysis and filter banks [8], which offer a solution to this important limitation. In addition, they deliver better results than the previous ones [11]. These methods are implementations of the ARSIS concept, a French acronym “Amélioration de la Résolution Spatiale par Injection de Structures” which means improvement of spatial resolution by structure injection [9]. This paper describes a modular software platform, written in IDL (Interactive Data Language) and dedicated to fusion of images within the ARSIS concept. As the needs of users differ from each others since users have their own purpose and opinion about what a fused image of good quality should be [4], the idea was to develop an application able to explore several fusion strategies. In addition, we needed to implement tools providing a complete assessment of the quality of fused products.

The articulation of the software is modular and new models can be added. It has innovative data structure and handling well-adapted to multi-resolution approaches. It thus constitutes a valuable tool for benchmarking and development of further models, tools and strategies.

2. THE FUSION ALGORITHMS WITHIN THE ARSIS CONCEPT

The ARSIS concept is based on multi-scale techniques to inject the missing high frequencies into the low resolution image [13]. Multi-scale techniques refer to mathematic tools such as convolution and numerical filtering. These tools undertake a hierarchical decomposition of the spatial information content of an image. The ARSIS concept assumes that the missing information is related to the high frequencies, and determines a relation between these frequencies and those to be injected, taking into account the characteristic of the sensors. The preponderant step of

ARSIS-type fusion is the modeling or synthesis of the missing information in the multispectral sensors. Most ARSIS implementations found in literature call for a pyramidal representation, as represented in the following illustration (figure 1). A fusion process begins with a multi-resolution analysis using a Multi-Scale Model (MSM). In

the general case, we denote h as the highest resolution (resolution of the Pan image which is not available in the MS data set), and $l, v, n...$ the successive coarser approximations. In order to simplify figure 1, we call A_0 the original Pan image and A_1, A_2, A_3, \dots its approximations at coarser resolutions.

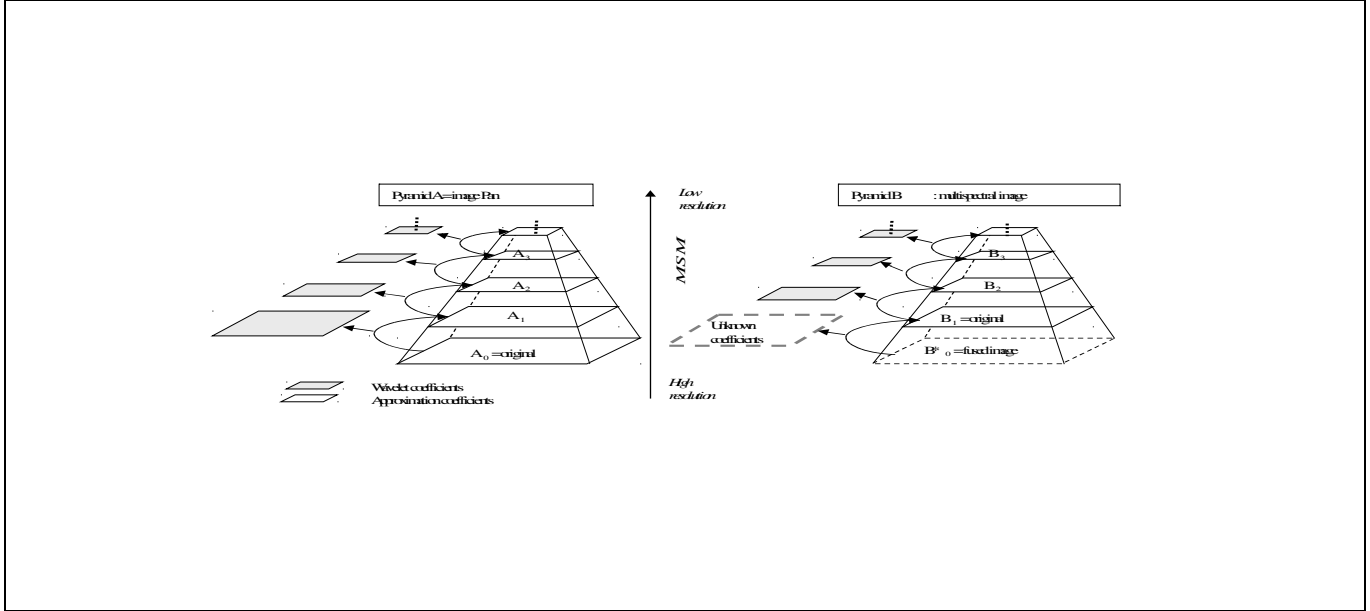


Figure 1. Scheme of a fusion within the ARSIS concept, using a pyramidal approach

As the multispectral (MS) image has a lower original resolution than the Pan one, let B_1 be the original MS image and B_2, B_3, B_4, \dots the successive coarser approximations of the MS image. The superscript $*$ in B^*_0 means that this level 0 is synthesized in the fusion process.

The decomposition is applied to both images (A_0 and B_1). A scale by scale spatial content description is obtained. According to the theory of multiresolution analysis of [7], an image can be reconstructed without loss from its coarser representation and its corresponding wavelet images or planes. So if the missing (or unknown) coefficients between the two lower levels of the pyramid B are known, the multispectral image can be perfectly recovered (dashed image). Hence, the challenge is to infer these unknown coefficients. This can be done by defining a relationship between the known levels of both pyramids, called Inter-Modality Model (IMM), and then by determining to what extent this relationship can be applied to the highest resolution, using a function called HRIMM for High Resolution IMM ([13], figure 2).

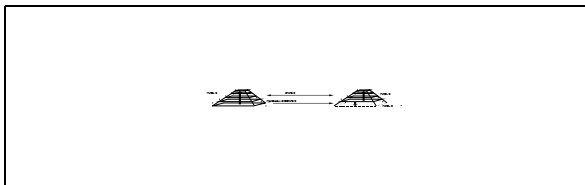


Figure 2. The three categories of models

Our platform is composed of different models within each category of models: MSM, IMM and HRIMM. Each model can be associated with other models of the two other categories, offering a great variety of strategies for fusion. Of course, some constraints exist that reduce the number of possible strategies. For instance, a pixel-based IMM (or “local” IMM) should not be followed by an image-based HRIMM (or “global” HRIMM). Another constraint is that the inverse MSM (MSM^{-1}) should be the same model than the MSM, in order to satisfy the lossless reconstruction property.

Three models are available in the category MSM: the undecimated wavelet transform (UWT [5]), the decimated wavelet transform (DWT [7]) and the Laplacian pyramid (LP [1]).

Concerning the IMM and HRIMM, three models offering a global approach (M1, M2 and M3 [9]), and one model using a local approach (RWM [8]) were implemented.

3. A PROTOCOL FOR QUALITY ASSESSMENT

Our platform comprises modules for the assessment of the quality of fused products. This part is not limited to products resulting from the fusion methods in the ARSIS concept; it can also be applied to images fused by the means of other techniques like IHS [2], PCA [10] or HPF [3]. We have adopted the protocol proposed by [12] and under approval

by the working group “data fusion” of the European Association of Remote Sensing Laboratories (EARSeL). It is based on the solid works of [6] [14] which paved the way to the determination of a normative framework where the procedure and indexes would be commonly-adopted to assess the expected benefits of a method or a fused product. This protocol comprises the checking of two properties: the consistency property and the synthesis property. The consistency property says that the fused product ($B^*_{i_0}$ in Figure 1) should be equal to the original data set (B_i) after being downsampled to its original low resolution 1 -let’s note ($B^*_{i_0}$)₁ the created image-. The synthesis property states that the fused MS image at the highest resolution reached with the fusion process h should be equal to a reference. The recurrent problem of reference has been tackled in [6] [12] [14], where a change of resolutions is proposed; original data sets are downsampled to reach lower resolution (respectively 1 for Pan and 2 for MS). Fusion is performed on these two new sets in order to obtain a fused version at the original low resolution of the MS images, so that the reference is obviously the original MS set. Monospectral and multispectral quality assessed at this low resolution is assumed to be close to the one found at the highest resolution.

These two properties must be checked both from the monospectral and multispectral point of view, and should be performed using qualitative (visual analysis) and quantitative criteria.

The quality assessment comprises four operations [12]:

First Operation. Perform the fusion process on the data sets A_0 and B_i . Obtain a set $B^*_{i_0}$.

Second Operation. Resample the set $B^*_{i_0}$ down to resolution 1. Check the consistency property by comparing B_i and ($B^*_{i_0}$)₁.

Third Operation. Resample the data sets A_0 and B_i down to respectively A_1 and B_2 . Perform the fusion process on these new data sets. Obtain a set $B^*_{i_1}$.

Fourth Operation. Check the synthesis property by comparing B_i and $B^*_{i_1}$, and assume that the synthesis quality assessed with $B^*_{i_1}$ is equivalent to that of $B^*_{i_0}$.

Our platform provides some characterization of both the mono and multispectral quality of a fused data set. These two modules, respectively called “Quality Assessment monospectral” and “Quality Assessment multispectral” can be used either at the end of a fusion process within the platform, using reference and resulting fused images as inputs, or as a single procedure, where inputs are images resulting from an external fusion process.

4. THE PYRAMIDAL STRUCTURE OF DATA

Data handling is an important aspect in a fusion process. We have developed a pyramidal structure for data that fits the pyramidal aspect of the information in the multi-resolution analysis (figure 3). This structure comprises the original

images as well as those resulting from the MSM model and a number of attributes of these images.

The MSM, specified by the user, takes as inputs the original image, its initial resolution, the number of iterations to decompose. The structure is divided into two main branches: on the one hand, the first branch “iter” carries the actual images (approximations and detail planes) created at coarser spatial resolutions, and on the other hand, “def” gives all the definitions linked to the decomposition, like the successive resolution or the edge to extract.

This structure is very convenient and offers a simple means to describe an image at various resolutions within the IDL operations.

5. USAGE AND EXAMPLES

The platform has three possible uses, as illustrated in Figure 4:

- launch the fusion process and then call the quality assessment;
- launch the fusion process only;
- launch the quality assessment only.

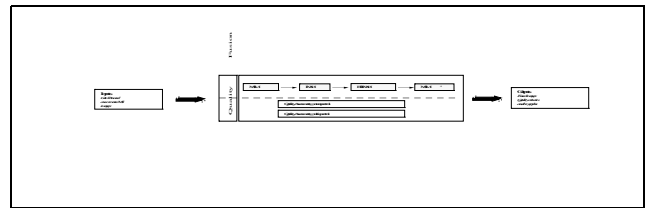


Figure 4. Scheme of the use of the platform.

Models can be associated to produce a fused image. As an example, we have adopted the following strategy: model UWT (MSM) + model M2 (IMM) + model M2 (HRIMM), and have applied it to an image acquired by the satellite Quickbird over the city of Frederikton, Canada. For the purpose of demonstration, the original data were spatially degraded by a factor 4: Pan from 0.7 to 2.8 m, and MS from 2.8 to 11.2 m. MS images were synthesized at 2.8 m, starting from 11.2 m, and compared to the original MS images. Figure 5 displays the original and the fused images for the red modality. One may observe that the fused image is close to the original one as expected, though it offers sharper details. The fused product is convenient for image analysis. Nevertheless, it derives from what should be observed by the same sensor but with the appropriate resolution.

Table 1 provides some statistical quantities for each modality. The bias is the difference between mean values and should be null. Here, we obtain very low values, compared to gray levels ranging from 0 to 1023. Standard-deviation is low for each modality. The correlation is computed between the original and fused images for each modality; it characterizes the synthesis of the high

frequencies. The value ranges between 0.945 and 0.958, in full agreement with the visual observation.

Modalities	Blue	Green	Red	Infrared
Bias	-0.19	-0.29	-0.20	0.31
Standard deviation	20.0	32.3	26.9	35.6
Correlation coefficient	0.945	0.957	0.958	0.958

Table 1: Statistics of the image of difference for monomodal quality.

For multimodal quality, we present here the index ERGAS [8] [14]. If $M(B_k)$ is the mean value for the modality k , then the ERGAS is defined by

$$ERGAS = 100 \frac{h}{l} \sqrt{\frac{1}{N} \sum_{k=1}^N \left(\frac{RMSE(B_k)}{M(B_k)} \right)^2}$$

It is equal here to 3.0. [8] [14] indicate that a value of 3 or lower means a good quality.

6. CONCLUSION

The combination of different models leads to different results [8] [4]. This platform has been developed in order to assess various combinations. It represents a convenient tool because more strategies can be added and tested, thanks to the opportunity to draw a complete assessment of the visual and quantitative quality of a fused products. The effort is underway to consolidate the IDL software. It is planned to make it public.

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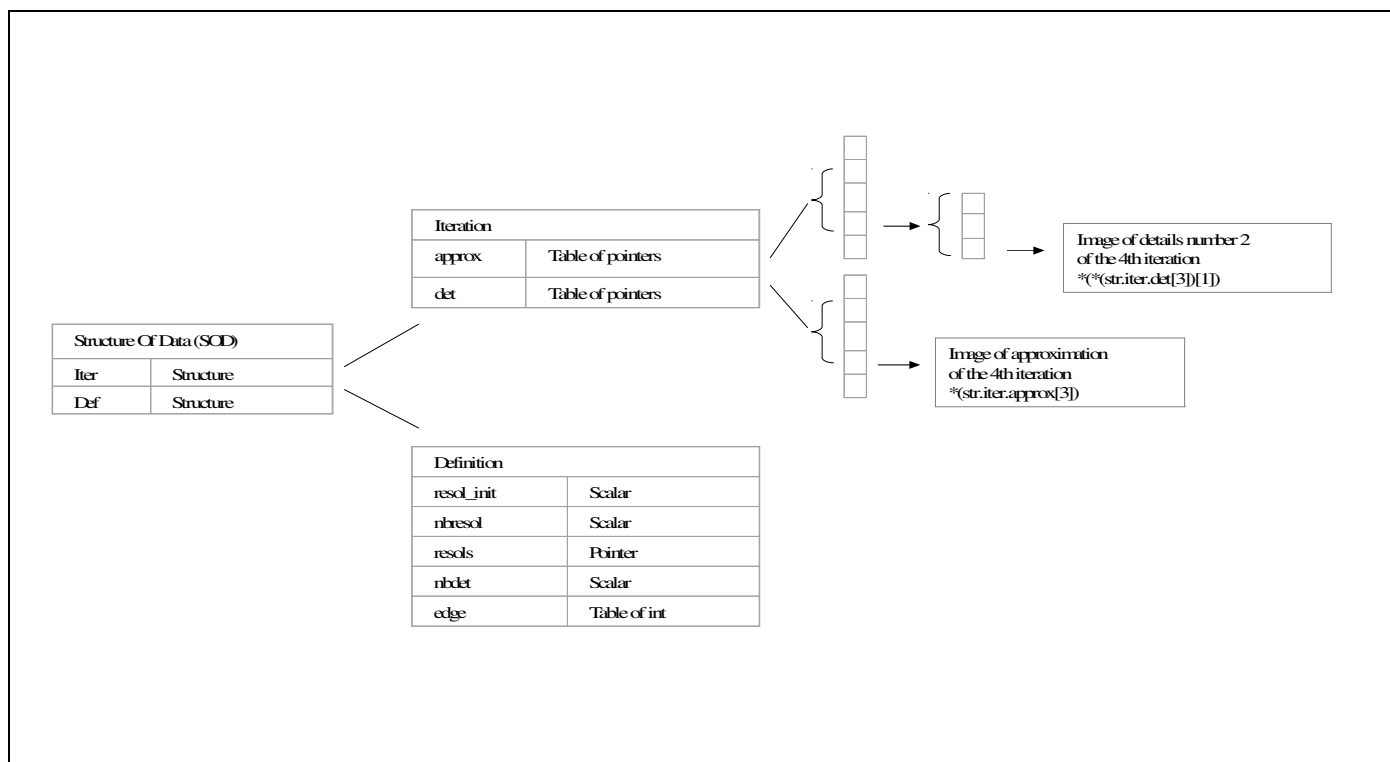


Figure 3 : SOD



Figure 5: Quickbird image of Fredrickton, Canada. Red modality, resolution 2.8 m. On the left, original image, copyright DigitalGlobe 2002. On the right, fused image.